SEMICONDUCTORS

THE INTEGRATED CIRCUIT

If the water pipe analogies of the resistor, diode, transistor, and very small capacitors could be etched into a single block of steel you would have the equivalent of the Integrated Circuit in Electronics. Figure 31 represents such a device. This block of steel would have to be very large to include all the mechanical parts needed. In electronics, the actual size of a diode or transistor is extremely small. In fact, millions can be fabricated on a piece of silicon no larger than the head of a pin. Photographic reduction techniques are used to generate the masking needed to isolate each part. These masks are then stepped and repeated in order to make many separate integrated circuits at the same time on a single substrate. Using mass production techniques, these circuits are manufactured, packaged, and sold at prices much lower than the equivalent discreet circuit would cost.

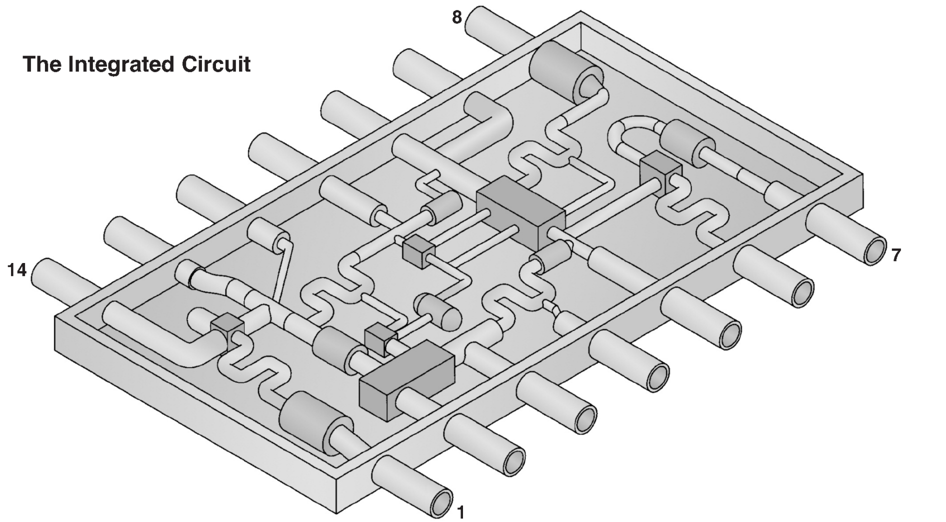


Figure 31

SEMICONDUCTOR SYMBOLS

Figure 32 shows the common symbols used in electronics to represent the basic components. Integrated Circuits are usually drawn as blocks with leads or as a triangle for operational amplifiers. The Zener diode (voltage reference diode) is used in the reverse direction at the point of breakdown.

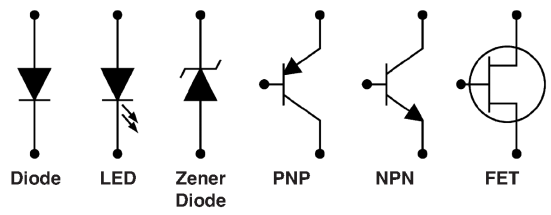
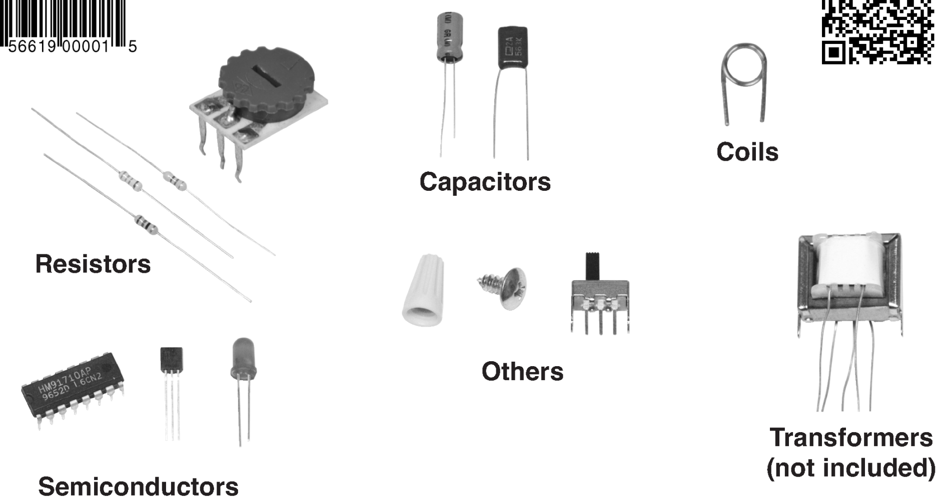


Figure 32

BASIC ELECTRONIC COMPONENTS

MODEL ECK-10



Instruction Manual

by Arthur F. Seymour MSEE

It is the intention of this course to teach the fundamental operation of basic electronic components by comparison to drawings of equivalent mechanical parts. It must be understood that the mechanical circuits would operate much slower than their electronic counterparts and one-to-one correlation can never be achieved. The comparisons will, however, give an insight to each of the fundamental electronic components used in every electronic product.

ELENCO®

RESISTORS

RESISTORS, *What do they do?*

The electronic component known as the resistor is best described as electrical friction. Pretend, for a moment, that electricity travels through hollow pipes like water. Assume two pipes are filled with water and one pipe has very rough walls. It would be easy to say that it is more difficult to push the water through the rough-walled pipe than through a pipe with smooth walls. The pipe with rough walls could be described as having more resistance to movement than the smooth one.

Pioneers in the field of electronics thought electricity was some type of invisible fluid that could flow through certain materials easily, but had difficulty flowing through other materials. In a way they were correct since the movement of electrons through a material cannot be seen by the human eye, even with the best microscopes made. There is a similarity between the movement of electrons in wires and the movement of water in the pipes. For example, if the pressure on one end of a water pipe is increased, the amount of water that will pass through the pipe will also increase. The pressure on the other end of the pipe will be indirectly related to the resistance the pipe has to the flow of water. In other words, the pressure at the other end of the pipe will decrease if the resistance of the pipe increases. Figure 1 shows this relationship graphically.

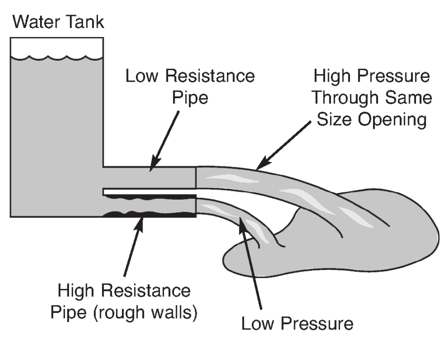


Figure 1

Electrons flow through materials when a pressure (called voltage in electronics) is placed on one end of the material forcing the electrons to “react” with each other until the ones on the other end of the material move out. Some materials hold on to their electrons more than others making it more difficult for the electrons to move. These materials have a higher resistance to the flow of electricity (called current in electronics) than the ones that allow electrons to move easily. Therefore, early experimenters called the materials *insulators* if they had very high resistance to electon flow and *conductors* if they had very little resistance to electron flow. Later materials that offered a medium amount of resistance were classified as *semiconductors*.

When a person designs a circuit in electronics, it is often necessary to limit the amount of electrons or current that will move through that circuit each second. This is similar to the way a faucet limits the amount of water that will enter a glass each second. It would be very difficult to fill a glass without breaking it if the faucet had only two states, wide open or off. By using the proper value of resistance in an electronic circuit designers can limit the pressure placed on a device and thus prevent it from being damaged or destroyed.

SUMMARY: The resistor is an electronic component that has electrical friction. This friction opposes the flow of electrons and thus reduces the voltage (pressure) placed on other electronic components by restricting the amount of current that can pass through it.

SEMICONDUCTORS

THE PNP TRANSISTOR

Figure 29 represents the water pipe equivalent of a PNP transistor. The emitter releases current that splits into two paths. The base current “forces open” the collector check valve which collects all the current except the small amount that goes into the base. The direction of current in the PNP transistor is opposite that of the NPN transistor. Because of these differences, the emitter of the PNP is usually referenced to the power supply voltage and the emitter of the NPN is usually referenced to ground or zero voltage. In both transistors, the current amplification factor (I_c/I_b) is called Beta (β).

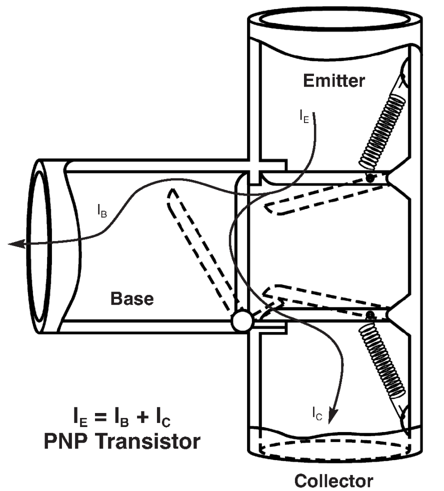


Figure 29

THE FIELD EFFECT TRANSISTOR

In Figure 30 the center of a small section of a pipe is made of thin, flexible rubber and that rubber is surrounded by water from a third pipe called the gate. When pressure is applied to the gate, the rubber pinches off the current from the source to the drain. No current flows from gate to drain or source. This device uses a change in gate pressure to control the current flowing from source to drain. Since there are no check valves, the current can flow in either direction. In other words, this device acts like a variable resistor. The Field Effect Transistor (FET) also controls current between source and drain by “pinching off” the path between them. The level of voltage on the gate controls the amount of current that will flow. Since no DC current flows in or out of the gate (only momentarily a small amount will flow to adjust to new pressures as in a capacitor), the power used by the gate is very close to zero. Remember, power equals voltage times current, and if the current is zero, the power is zero. This is why FETs are used in the probes of test equipment. They will not disturb the circuit being tested by removing power during a measurement. When a second gate section is added (pipe and rubber) between the source and drain it is called a Dual Gate FET. In our water pipe analogy of the FET transistor, the rubber must be very thin and flexible in order to “pinch off” the current from the source to the drain. This means it could be easily damaged by a small “spike” of high pressure. The same is true of an electronic FET. A high voltage “spike” (Static Electricity) can destroy the gate and ruin the FET. To protect the FET, they are sometimes packaged with metal rings shorting their leads, and a fourth lead may be added to the metal case containing the transistor.

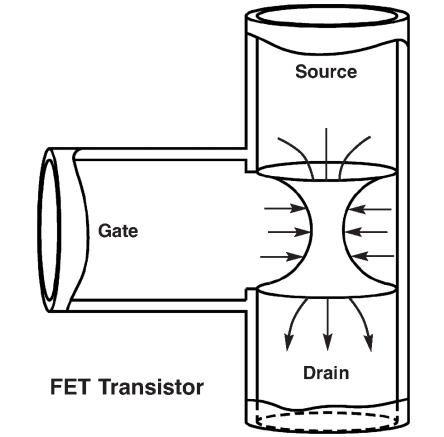


Figure 30

SEMICONDUCTORS

THE DIODE, *what is it?*

The diode can be compared to the check valve shown in Figure 26. The basic function of a check valve is to allow water to flow in only one direction. Once the force of the spring is exceeded, the plate moves away from the stop allowing water to pass through the pipe. A flow of water in the opposite direction is blocked by the solid stop and plate. If it took a pressure of 0.7lb to exceed the spring force, the flow of water versus pressure might look like Figure 27. In electronics, this curve would represent the typical silicon diode if pounds per square inch equaled volts and gallons per minute equaled amperes. Of course, the amount of current that flows through the diode must be limited or the device could be damaged. Just as too much water through the check valve could destroy the plate (shorted diode). If the diode is made of Gallium Arsenide, it would take approximately twice the voltage to produce a flow of current (spring in Figure 26 is twice as strong). The energy level required to "turn on" a Gallium Arsenide diode is so high, that light is generated when current starts to flow. These diodes are called "Light Emitting Diodes", or simply LEDs.

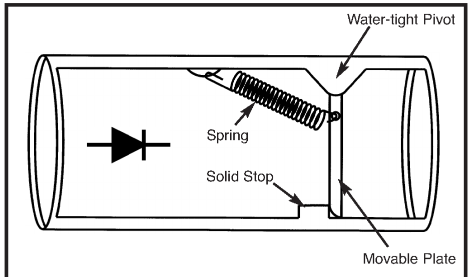


Figure 26

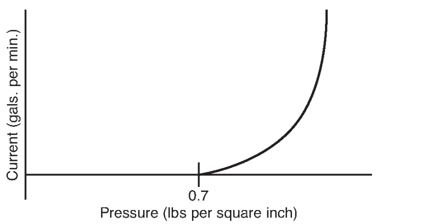


Figure 27

THE TRANSISTOR, *what is it?*

The transistor is best described as a device that uses a small amount of current to control a large amount of current (Current Amplifier). Consider a device fabricated as shown in Figure 28. A small amount of "Base Current" pushes on the L_1 portion of the lever arm forcing check valve D_1 to open, even though it is "reverse biased" (pressure is in direction to keep check valve shut). Keep in mind the base current would not start to flow until the check valve D_2 allowed current to flow (0.7lb). If the current ratio through D_1 and Base was equal to the lever arm advantage, then $I_1 / I_b = L_1 / L_2$. Call this ratio Beta (β) and let L_1 = 1 inch and L_2 = 0.01 inch. Then $\beta = 100$ and I_1 will be 100 times I_b. Since both currents must pass through D_2, $I_2 = I_1 + I_b$. These same principles apply to a silicon NPN transistor. I_1 becomes collector current (I_C), and I_2 would be emitter current (I_E). $\beta = I_C / I_B$ and $I_E = I_B + I_C$.

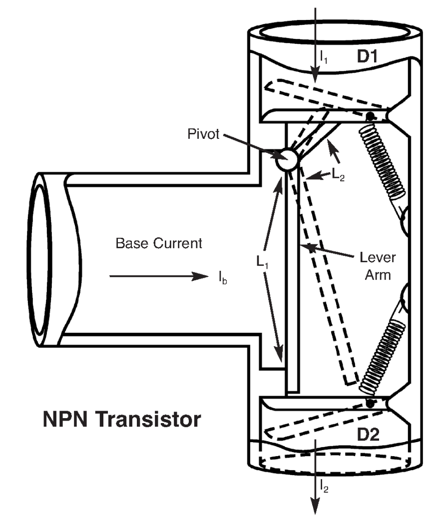


Figure 28

RESISTORS

RESISTORS, *How are they made?*

There are many different types of resistors used in electronics. Each type is made from different materials. Resistors are also made to handle different amounts of electrical power. Some resistors may change their value when voltages are placed across them. These are called voltage dependent resistors or *nonlinear* resistors. Most resistors are designed to change their value when the temperature of the resistor changes. Some resistors are also made with a control attached that allows the user to mechanically change the resistance. These are called variable resistors or potentiometers. Figure 2 shows physical shapes of some different types of resistors.

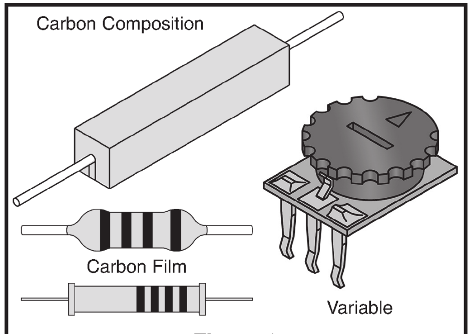


Figure 2

THE WIREWOUND RESISTOR

The first commercial resistors made were formed by wrapping a resistive wire around a non-conducting rod (see Figure 3). The rod was usually made of some form of ceramic that had the desired heat properties since the wires could become quite hot during use. End caps with leads attached were then placed over the ends of the rod making contact to the resistive wire, usually a nickel chromium alloy.

The value of wirewound resistors remain fairly flat with increasing temperature, but change greatly with frequency. It is also difficult to precisely control the value of the resistor during construction so they must be measured and sorted after they are built.

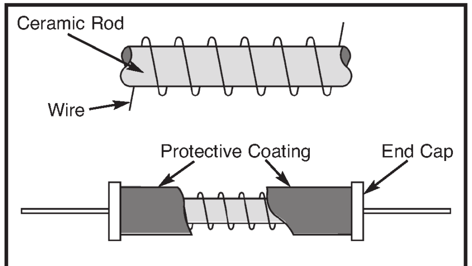


Figure 3

THE CARBON COMPOSITION RESISTOR

By grinding carbon into a fine powder and mixing it with resin, a material can be made with different resistive values. Conductive leads are placed on each end of a cylinder of this material and the unit is then heated or cured in an oven. The body of the resistor is then painted with an insulating paint to prevent it from shorting if touched by another component. The finished resistors are then measured and sorted by value (Figure 4). If these resistors are overloaded by a circuit, their resistance will permanently decrease. It is important that the power rating of the carbon composition resistor is not exceeded.

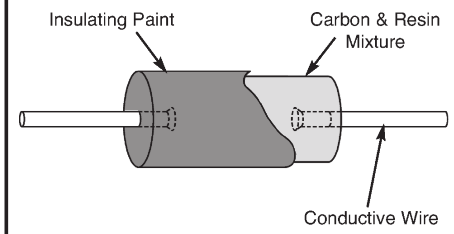


Figure 4

RESISTORS

CARBON FILM RESISTORS

Carbon film resistors are made by depositing a very thin layer of carbon on a ceramic rod. The resistor is then protected by a flameproof jacket since this type of resistor will burn if overloaded sufficiently. Carbon film resistors produce less electrical noise than carbon composition and their values are constant at high frequencies. You can substitute a carbon film resistor for most carbon composition resistors if the power ratings are carefully observed. The construction of carbon film resistors require temperatures in excess of 1,000°C.

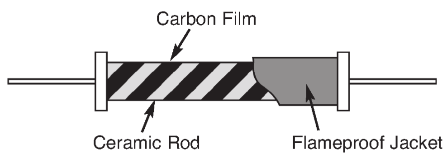


Figure 5

METAL OXIDE RESISTORS

Metal oxide resistors are also constructed in a similar manner as the carbon film resistor with the exception that the film is made of tin chloride at temperatures as high as 5,000°C. Metal oxide resistors are covered with epoxy or some similar plastic coating. These resistors are more costly than other types and therefore are only used when circuit constraints make them necessary.

METAL FILM RESISTORS

Metal film resistors are also made by depositing a film of metal (usually nickel alloy) onto a ceramic rod. These resistors are very stable with temperature and frequency, but cost more than the carbon film or carbon composition types. In some instances, these resistors are cased in a ceramic tube instead of the usual plastic or epoxy coating.

THE VARIABLE RESISTOR

When a resistor is constructed so its value can be adjusted, it is called a variable resistor. Figure 6 shows the basic elements present in all variable resistors. First a resistive material is deposited on a non-conducting base. Next, stationary contacts are connected to each end of the resistive material. Finally, a moving contact or wiper is constructed to move along the resistive material and tap off the desired resistance. There are many methods for constructing variable resistors, but they all contain these three basic principles.

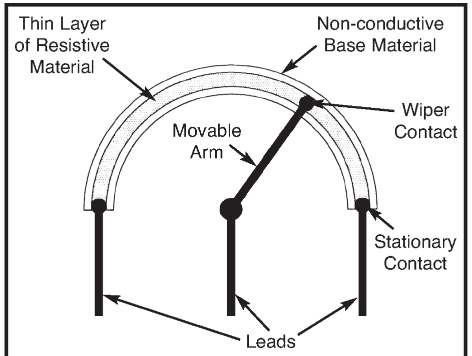


Figure 6

INDUCTORS

TWO MORE LAWS ABOUT INDUCTORS

Faraday's Law states that any time a conductor moves through a magnetic field (Figure 23) a voltage is generated. Because of this principle, it is possible to attach a magnet (or coil) to a rotating device and produce large amounts of electrical power (the Hoover Dam for example).

Lenz' Law states that the induced currents in a conductor passing through a magnetic field will produce a magnetic field that will oppose the motion between the magnet and the conductor. To produce a large amount of electrical power, a large mechanical force is required (conservation of power).

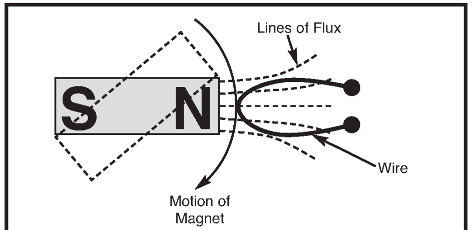


Figure 23

INDUCTANCE SYMBOLS AND MARKINGS

Most inductors are custom made to meet the requirements of the purchaser. They are marked to match the specification of the buyer and therefore carry no standard markings. The schematic symbols for coils and transformers are shown in Figure 24. These symbols are the most commonly used to represent fixed coils, variable coils, and transformers.

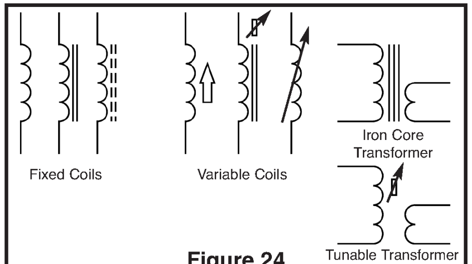


Figure 24

THE Q FACTOR IN COILS $\frac{X_L}{r}$

The Q (figure of merit) of a coil is the ratio of the inductive reactance to the internal series resistance of the coil. Since the reactance and resistance can both change with frequency, Q must be measured at the desired frequency. Anything that will raise the inductance without raising the series resistance will increase the Q of the coil; for example, using an iron core. Lowering the series resistance without lowering the inductance will also raise the Q, more turns of larger wire for example. Q is important when the inductor is used in a resonant circuit to block or select desired frequencies. The higher the Q, the tighter the selection of frequencies become.

SUMMARY

The Inductor prevents current from making any sudden changes by producing large opposing voltages. Magnetic coupling can be used to transform voltages and currents, but power must remain the same. Coils and transformers can be used to select frequencies.

INDUCTORS

INDUCTANCE, *How is it calculated?*

Reviewing how coils are made will show the following:

1. Inductance of a coil is indirectly proportional to the length of the coil.
2. Inductance is directly proportional to the cross sectional area.
3. Inductance is proportional to the square of the number of turns.
4. Inductance is directly proportional to the permeability of the core material.

From the above information the formula for inductance of a simple iron core would be:

$$L = \frac{N^2 \mu A}{10 \ell}$$

Where:

L = Inductance in microhenrys

N = Number of turns

μ = Permeability of core material

A = Cross-sectional area of coil, in square inches

ℓ = Length of coil in inches

This formula is good only for solid core coils with length greater than diameter.

TRANSFORMERS, *How are they made?*

Placing different coils on the same iron core as shown in Figure 22 produces the electronic component known as the Transformer. If a DC current is forced through the center coil, the other two coils will only produce a current when the original current is changing. Once the DC current reaches a constant value, the other two coils will "unlink" and produce no flowing current if loaded. If the generator voltage is continuously changing as in Figure 22, it will produce a current that changes with time. This changing current in the center coil will produce similar currents in both of the end coils. Since the bottom coil has twice the number of turns (twice the magnetic linkage), the voltage across this coil will be twice the generator voltage. The power in an electronic device is equal to the voltage across the device times the current through the device (P=VI). If the voltage doubles on the bottom winding, then the current must become 1/2 due to the law of conservation of power (Power cannot be created or destroyed, but can be transformed from one state to another). Since the bottom coil is wound in the same direction as the generator coil, the voltage across the coil (top wire to bottom wire) will be the same polarity as the generator voltage. The top coil is wound in the opposite direction forcing the core magnet rotation (Called flux by the Pros) to push the current in the opposite direction and produce a voltage of the opposite polarity. Since the number of turns in the top coil are the same as the generator coil, the voltage and current (Power that can be taken from the coil) will also be equal. This ability to transform AC voltages and AC currents influenced early experimenters to call this device a Transformer.

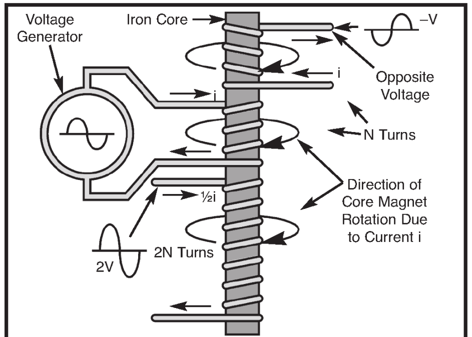


Figure 22

RESISTORS

RESISTOR VALUES AND MARKINGS

The unit of measure for resistance is the ohm, which is represented by the Greek letter Ω. Before technology improved the process of manufacturing resistors, they were first made and then sorted. By sorting the values into groups that represented a 5% change in value, (resistor values are 10% apart), certain preferred values became the standard for the electronics industry. Table 1 shows the standard values for 5% resistors.

10	11	12	13	15	16	18	20
22	24	27	30	33	36	39	43
47	51	56	62	68	75	82	91

Table 1

Resistors are marked by using different colored rings around their body (see Figure 7). The first ring represents the first digit of the resistor's value. The second ring represents the second digit of the resistor's value. The third ring tells you the power of ten to multiply by. The final and fourth ring represents the tolerance. For example, gold is for 5% resistors and silver for 10% resistors. This means the value of the resistor is guaranteed to be within 5% or 10% of the value marked. The colors in Table 2 are used to represent the numbers from 0 to 9.

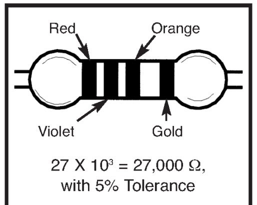


Figure 7

COLOR	VALUE
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

Table 2

BAND 1 1st Digit	
Color	Digit
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

BAND 2 2nd Digit	
Color	Digit
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

Multiplier	
Color	Multiplier
Black	1
Brown	10
Red	100
Orange	1,000
Yellow	10,000
Green	100,000
Blue	1,000,000
Silver	0.01
Gold	0.1

Resistance Tolerance	
Color	Tolerance
Silver	±10%
Gold	±5%
Brown	±1%
Red	±2%
Orange	±3%
Green	±.5%
Blue	±.25%
Violet	±.1%

Note: If the third ring is gold, you multiply the first two digits by 0.1 and if it is silver, by 0.01. This system can identify values from 0.1Ω to as high as 91 x 10^9, or 91,000,000,000Ω. The amount of power each resistor can handle is usually proportional to the size of the resistor. Figure 8 shows the actual size and power capacity of normal carbon film resistors, and the symbols used to represent resistors on schematics.

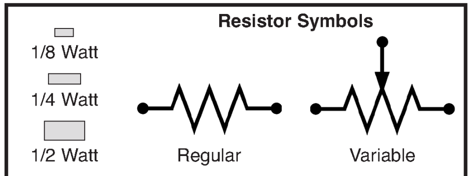


Figure 8

CAPACITORS

CAPACITORS, *What do they do?*

Capacitors are components that can store electrical pressure (Voltage) for long periods of time. When a capacitor has a difference in voltage (Electrical Pressure) between its two leads it is said to be charged. A capacitor is charged by forcing a one way (DC) current to flow through it for a short period of time. It can be discharged by letting an opposite direction current flow out of the capacitor. Consider for a moment the analogy of a water pipe that has a rubber diaphragm sealing off each side of the pipe as shown in Figure 9.

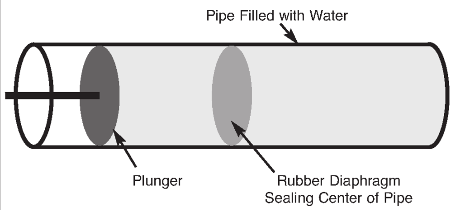


Figure 9

If the pipe had a plunger on one end, as shown in Figure 9, and the plunger was pushed toward the diaphragm, the water in the pipe would force the rubber to stretch out until the force of the rubber pushing back on the water was equal to the force of the plunger. You could say the pipe is charged and ready to push the plunger back. In fact, if the plunger is released it will move back to its original position. The pipe will then be discharged or with no charge on the diaphragm.

Capacitors act the same as the pipe in Figure 9. When a voltage (Electrical Pressure) is placed on one lead with respect to the other lead, electrons are forced to "pile up" on one of the capacitor's plates until the voltage pushing back is equal to the voltage applied. The capacitor is then charged to the voltage. If the two leads of that capacitor are shorted, it would have the same effect as letting the plunger in Figure 9 move freely. The capacitor would rapidly discharge and the voltage across the two leads would become zero (No Charge).

What would happen if the plunger in Figure 9 was wiggled in and out many times each second? The water in the pipe would be pushed by the diaphragm then sucked back by the diaphragm. Since the movement of the water (Current) is back and forth (Alternating) it is called an Alternating Current or AC. The capacitor will therefore pass an alternating current with little resistance. When the push on the plunger was only toward the diaphragm, the water on the other end of the diaphragm moved just enough to charge the pipe (transient current). Just as the pipe blocked a direct push, a capacitor clocks direct current (DC). An example of alternating current is the 60 cycle (60 wiggles each second) current produced when you plug something into a wall outlet.

SUMMARY: A capacitor stores electrical energy when charged by a DC source. It can pass alternating current (AC), but blocks direct current (DC) except for a very short charging current, called transient current.

INDUCTORS

INDUCTORS, *How are they made?*

In order to understand how inductors are made, we have to change our water pipe analogy slightly to include the effect of magnetic fields. Consider two pipes filled with water and small magnets attached to the walls of the pipes with rubber bands as shown in Figure 19. The moving magnets, due to the original current, pull the magnets in the second pipe and force a small current to flow in the same direction as the original current. When the rubber bands are fully stretched, the induced current will stop, even though the initial DC current is still flowing. If the original current is an AC current however, it will induce a continuous AC current in the second pipe because the magnets will move back and forth, pulling the magnets in the second pipe back and forth.

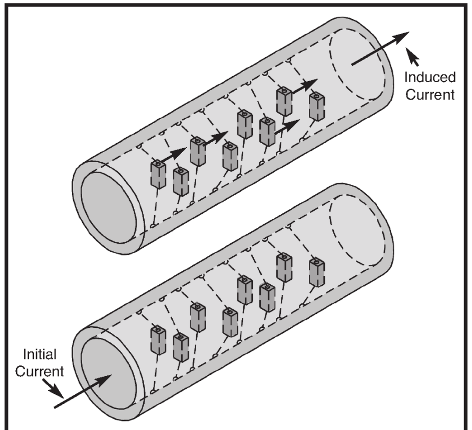


Figure 19

Consider the two coiled pipes shown in Figure 20. When the pipe is stretched out (increased length) as in coil 1, the adjacent turns have little affect on each other. In coil 2 (decreased length) the magnets in each turn of the pipe are linking and the amount of "apparent mass" in the pipe seems to increase. In an inductor, pushing the coiled wire closer together causes the inductance of the coil to also increase, and stretching the coil out will lower the inductance of the coil. In other words, the inductance of a coil is indirectly proportional to its length. If the diameter of the coil is increased, it will take more hose to form a loop, and the amount of water will therefore increase. More water means a larger "apparent mass". Inductance will also increase in a coil if the cross sectional area increases. Inductance is directly proportional to area.

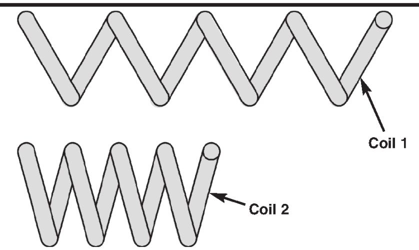


Figure 20

Consider the affect of adding more turns to coiled pipe. The amount of material to push (mass) is increased and the amount of linkage is increased due to more magnets available. This causes the "apparent mass" to increase at a greater rate than would be expected. When making an inductor, the actual inductance is directly proportional to the square of the number of turns.

The final factor to consider when making a coil is the core material at the center of the coil. If our pipe wrapped around a material that contained many magnets, they would also link to the magnets in the pipe. This would increase the "apparent mass" of the water in the pipe. The tiny magnets in the core would rotate as shown in Figure 21 and force the water to keep moving in the same direction. Placing an iron core at the center of an inductor will directly increase the inductance by an amount equal to the permeability of the core material.

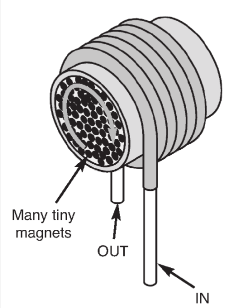


Figure 21

INDUCTORS

INDUCTORS, *What do they do?*

The electronic component known as the inductor is best described as electrical momentum. In our water pipe analogy the inductor would be equivalent to a very long hose that is wrapped around itself many times (see Figure 18). If the hose is very long it will contain many gallons of water. When pressure is applied to one end of the hose, the thousands of gallons of water would not start to move instantly. It would take time to get the water moving due to inertia (a body at rest wants to stay at rest). After a while the water would start to move and pick up speed. The speed would increase until the friction of the hose applied to the amount of pressure being applied to the water. If you try to instantly stop the water from moving by holding the plunger, the momentum (a body in motion wants to stay in motion) of the water would cause a large negative pressure (Suction) that would pull the plunger from your hands.

Since Inductors are made by coiling a wire, they are often called Coils. In practice the names Inductor and Coil are used interchangeably. From the above analogy, it is obvious that a coiled hose will pass Direct Current (DC), since the water flow increases to equal the resistance in the coiled hose after an elapsed period of time. If the pressure on the plunger is alternated (pushed, then pulled) fast enough, the water in the coil will never start moving and the Alternating Current (AC) will be blocked. The nature of a Coil in electronics follows the same principles as the coiled hose analogy. A coil of wire will pass DC and block AC. Recall that the nature of a Capacitor blocked DC and passed AC, the exact opposite of a coil. Because of this, the Capacitor and Inductor are often called Dual Components. Table 5 compares the properties of capacitors and inductors.

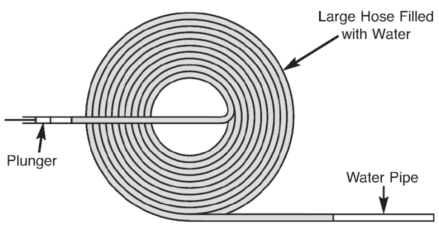


Figure 18

Capacitor	Inductor
Blocks Direct Current	Blocks Alternating Current
Passes Alternating Current	Passes Direct Current
Voltage in Capacitor cannot change instantly	Current in an Inductor cannot change instantly
Quick Voltage change produces large Current	Quick Current change produces large Voltage
Stores Energy in Electric Field	Stores Energy in Magnetic Field
Current leads Voltage	Voltage leads Current

Table 5

CAPACITORS

CAPACITORS, *How are they made?*

There are many different types of capacitors used in electronics. Each type is made from different materials and with different methods. Capacitors are also made to handle different amounts of electrical pressure or voltage. Each capacitor is marked to show the maximum voltage that it can withstand without breaking down. All capacitors contain the same fundamental parts, which consist of two or more conductive plates separated by a nonconductive material. The insulating material between the plates is called the dielectric. The basic elements necessary to build a capacitor are shown in Figure 10.

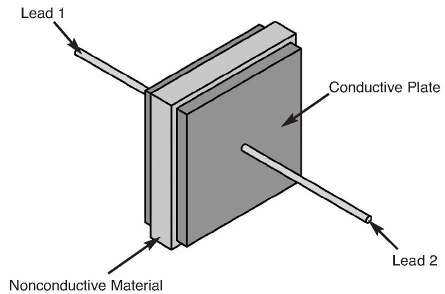


Figure 10

THE METAL FOIL CAPACITOR

Perhaps the most common form of capacitor is constructed by tightly winding two foil metal plates that are separated by sheets of paper or plastic as shown in Figure 11. By picking the correct insulating material the value of capacitance can be increased greatly, but the maximum working voltage is usually lowered. For this reason, capacitors are normally identified by the type of material used as the insulator or dielectric. Consider the water pipe with the rubber diaphragm in the center of the pipe. The diaphragm is equivalent to the dielectric in a capacitor. If the rubber is made very soft, it will stretch out and hold a large amount of water, but it will break easily (large capacitance, but low working voltage). If the rubber is made very stiff, it will not stretch far, but will be able to withstand higher pressure (low capacitance, but high working voltage). By making the pipe larger and keeping the stiff rubber we can achieve a device that holds a large amount of water and withstands a high amount of pressure (high capacitance, high working voltage, large size). These three types of water pipes are illustrated in Figure 12. The pipes follow the rule that the capacity to hold water, (Capacitance) multiplied by the amount of pressure they can take (Voltage) determines the size of the pipe. In electronics the CV product determines the capacitor size.

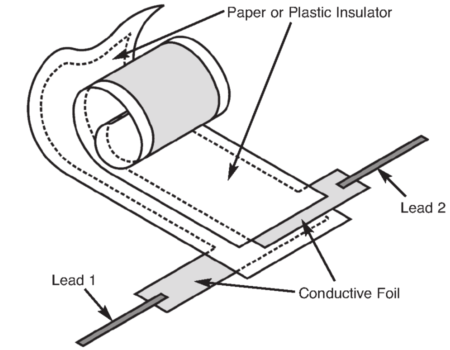


Figure 11

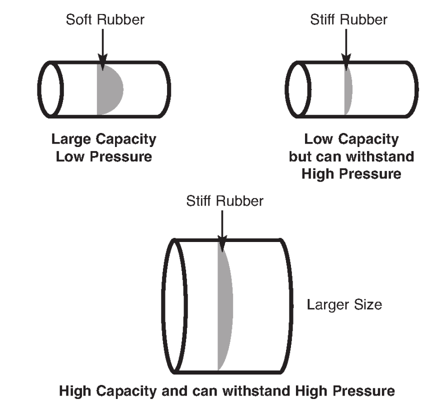


Figure 12

DIELECTRIC CONSTANT, *What is it?*

The dielectric (rubber diaphragm in the water pipe analogy) in a capacitor is the material that can withstand electrical pressure (Voltage) without appreciable conduction (Current). When a voltage is applied to a capacitor, energy in the form of an electric charge is held by the dielectric. In the rubber diaphragm analogy the rubber would stretch out and hold the water back. The energy was stored in the rubber. When the plunger is released the rubber would release this energy and push the plunger back toward its original position. If there was no energy lost in the rubber diaphragm, all the energy would be recovered and the plunger would return to its original position. The only perfect dielectric for a capacitor in which no conduction occurs and from which all the stored energy may be recovered is a perfect vacuum. The *DIELECTRIC CONSTANT* (K) is the ratio by which the capacitance is increased when another dielectric replaces a vacuum between two plates. Table 3 shows the Dielectric Constant of various materials.

Air, at normal pressure	1	Mica	7.5
Alcohol, ethyl (grain)	25	Paper, manila	1.5
Beeswax	1.86	Paraffin wax	2.25
Castor Oil	4.67	Porcelain	4.4
Glass flint density 4.5	10	Quartz	2
Glycerine	56	Water, distilled	81

Table 3

THE VARIABLE CAPACITOR

To make a variable capacitor, one set of stationary aluminum plates are mounted to a frame with a small space between each plate. Another set of plates are mounted to a movable shaft and designed to fit into the space of the fixed plates without touching them. The insulator or dielectric in this type of variable capacitor is air. When the movable plates are completely inside the fixed plates, the device is at minimum capacitance. The shape of the plates can be designed to achieve the proper amount of capacitance versus rotation for different applications. An additional screw is added to squeeze two insulated metal plates together (Trimmer) and thus set the minimum amount of capacitance.

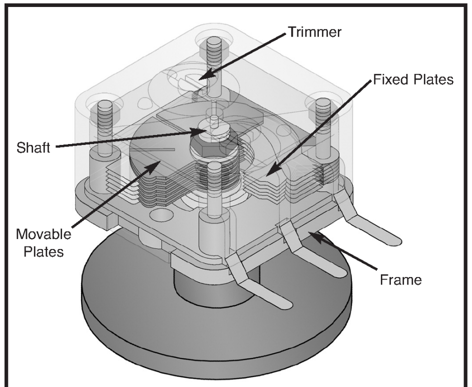


Figure 13

CAPACITANCE, *How is it calculated?*

The amount of charge a capacitor can hold (capacitance) is measured in Farads. In practice, one farad is a very large amount of capacitance, making the most common term used micro-farad or one millionth of a farad. There are three factors that determine the capacitance that exist between two conductive plates:

1. The bigger the plates are (Surface Area), the higher the capacitance. Capacitance (C) is directly proportional to Area (A).
2. The larger the distance is between the two plates, the smaller the amount of capacitance. Capacitance (C) is indirectly proportional to distance (d).
3. The larger the value of the dielectric constant, the more capacitance (Dielectric constant is equivalent to softness of the rubber in our pipe analogy). The capacitance (C) is directly proportional to the Dielectric Constant (K) of the insulating material. From the above factors, the formula for capacitance in Farads becomes:

$$C = 0.244K \frac{A(N-1)}{d} \text{ Picofarads *}$$

C = Capacitance in Picofarads (Farad x 10^{-12})

K = Dielectric Constant

A = Area of one Plate in square inches

N = Number of Plates

d = Distance between plates in inches

Example Calculation for Capacitor shown in Figure 14.
C = 2.24 x (1 x 1)(2 - 1) / (.01) = 224 Picofarads or 0.000224 Microfarads.

* If A and d are in centimeters change 0.224 to 0.0885.

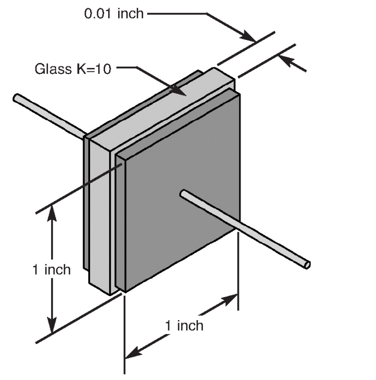


Figure 14

CAPACITOR VALUES AND MARKINGS

The older styles of capacitors were marked with colored dots or rings similar to resistors. In recent years, the advances in technology has made it easier to print the value, working voltage, tolerance, and temperature characteristics on the body of the capacitors. Certain capacitors use a dielectric that requires markings to insure one lead is always kept at a higher voltage than the other lead. Figure 15 shows typical markings found on different types of capacitors. Table 4 gives the standard values used and the different methods for marking these values.

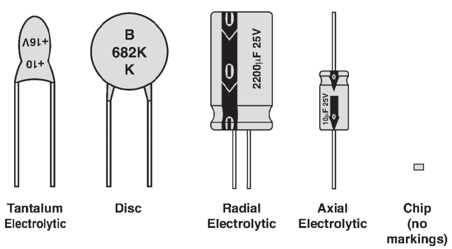


Figure 15